Generation of DTM using SPOT Image near Mt. Fuji by Digital Image Correlation

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ABSTRACT

The objective of this study is to estimate the accuracies of DTM generated by digital image correlation methods using three SPOT images near Mt. Fuji. The following three methods were applied for triplet SPOT images.

Method 1 : simply using stereo pair
Method 2-1 : eliminating mismatches using two stereo pairs
Method 2-2 : using the condition that three bundles have the same intersection point

As the result of this study, method 2-2 highly improve the accuracy that is 11 to 13m of Standard Deviation.

1. Introduction

SPOT satellite which was launched in 1986 enables us to make DTM and draw contour lines by digital image correlation. It will be a high possibility to draw precise contour lines, since the height of houses and trees are rather small compared with assumed contour interval using SPOT. In this study, three SPOT HRV images (level 1A) which have the different angles near Mt. Fuji were used to estimate the accuracy of DTM generated by image correlation.

2. Test Area and External Orientation

Figure 1 shows the area of three SPOT images and the test areas of DTM generated by image correlation. The size of three test areas are 2km x 4km. The ground features of the test areas are as follows.

Test area 1 : This area is mountainous with steep slopes. Some areas was covered with little snow.
Test area 2 : The center of this area is flat and each side of this area is mountainous.
Test area 3 : This area is the east part of Mt. Fuji and is covered with coniferous forest. The slope is gradually changing.

Figure 2 shows the dates and sensor angles of three SPOT images. Exterior orientation of SPOT Images was carried out and their accuracies of reference points were 9.5m for planimetric and 11.5m for height./1/ To evaluate the accuracies of DTM generated by image correlation, the grid spaced DTM's were acquired from the contour lines of 1:25,000 topographic maps.

Fiugre 1(a) Areas of SPOT Images

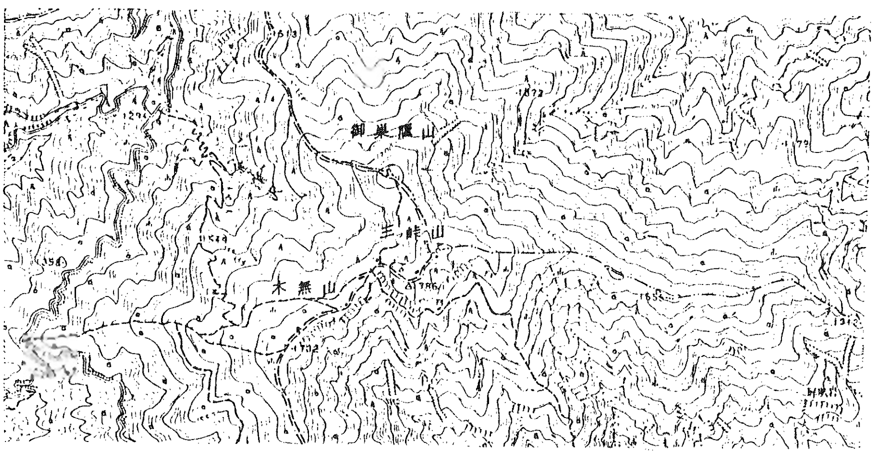

Figure 1(b) Test Area 1 (reduced to 1:35,000)

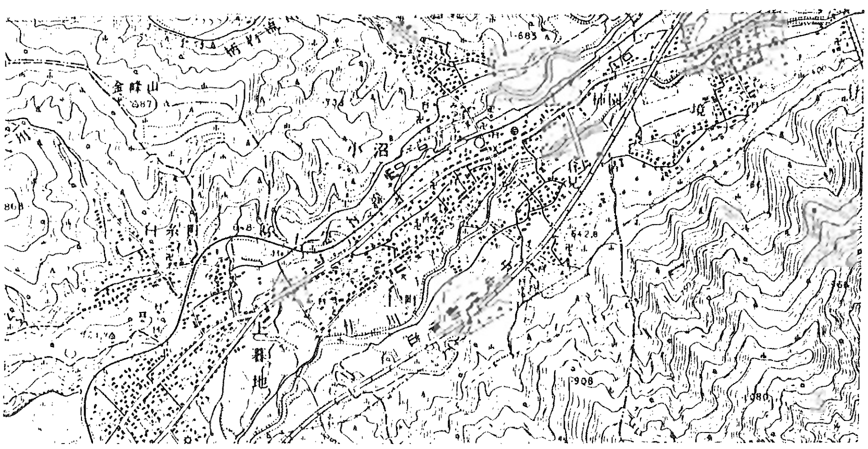

Figure 1(c) Test Area 2 (reduced to 1:35,000)

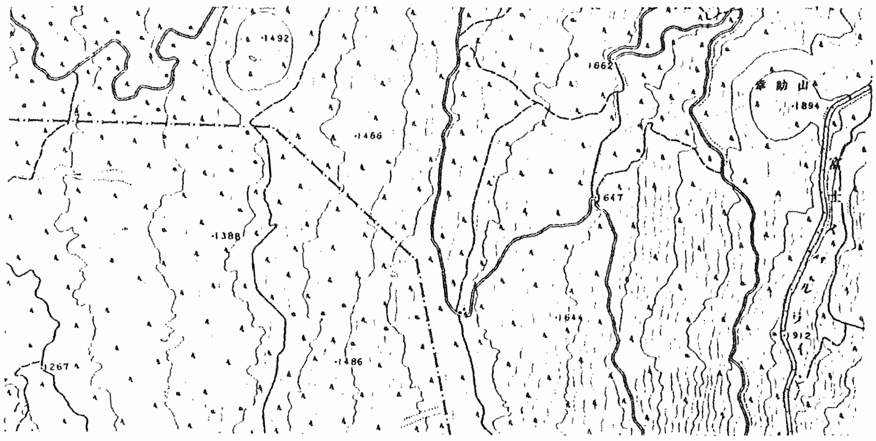

Figure 1(d) Test Area 3 (reduced to 1:35,000)

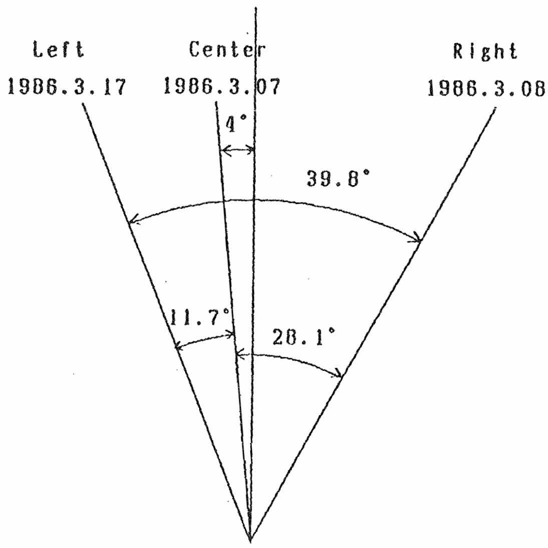

Figure 2 Stereo Angles of SPOT Image

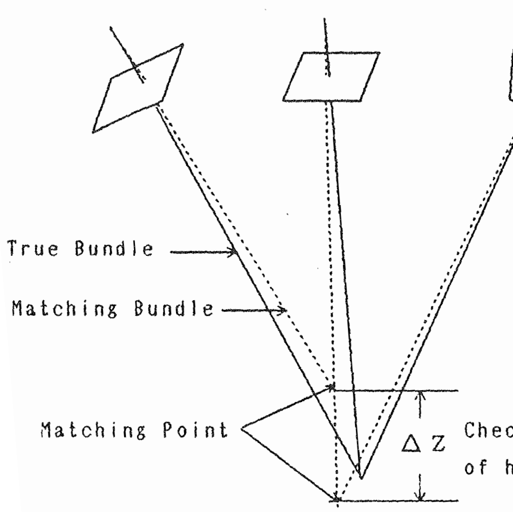

Figure 3(a)
Method of Eliminate Mismatching

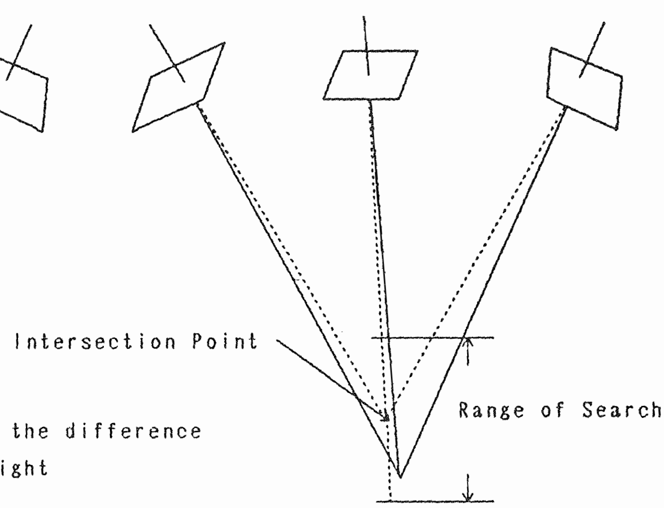

Figure 3(b)
Method of Same Intersection Point

3. Digital Image Correlation

3.1 Methods of Digital Image Correlation

In this study, normalized cross-covariances were used as for matching criterion of image correlation, since the gray levels of the three SPOT images are different. The y-parallaxes of three images were eliminated according to the parameter of exterior orientation, just before image correlation were computed.

Image correlation were simply applied for two stereo pairs (B/H=0.2 and 0.52). Additionary, following two methods were applied. Triplet SPOT images near Mt. Fuji have the redundancy of stereoscopic measurement. By using this redundancy, there will be a possibility to improve the accuracy of DTM. One method is eliminating mismatch with comparing the heights obtained from two stereo pairs. The other method is image correlation using the condition that three bundles have the same intersection point (Fig 3).

Additionary, using double windows which may avoid large error was applied.

In this study, following three image correlation methods were applied.

Method-1 Stereo-matching

Case 1-1 : Center and left image pair was used. (B/H=0.20)

Case 1-2 : Center and right image pair was used. (B/H=0.52)

* Left and right image pair (B/H=0.72) was not used, because of the distortion of two image was too large.

Method-2 Triplet-matching

Method 2-1 : Eliminate mismatching using two stereo pairs

Method 2-2 : Using the condition of same intersection point

3.2 Preliminary Test of Image Correlation

The preliminary test was applied to find the window size (nxn) which has good accuracies for a part of test area A. The effects of Median filter (3x3) was also tested for the DTM's generated by image correlation.

Table 1 shows the results of preliminary test. The error is a discrepancy that DTM from image correlation minus DTM from maps. The plus error means that the height from image correlation is higher than that from 1:25,000 maps. The RMSE is the root mean square error of discrepancy. The bias is the average discrepancy. Standard deviation means that root mean square error of discrepancy after removing bias. The followings were known from the preliminary test.

1) Median filter improved the accuracy about 30%.

2) The highest accuracy was given by the method 2-2 of 5x5 window size and using median filter. The standard deviation was 12.26m.

3) Case 1-1 (B/H=0.2) was more accurate than Case 1-2 (B/H=0.52). The reason may be that the quality of right image(8th March) is worse compared with other images.

4) The biases in this test area were -22 to -24m.

5) As for window size, 7x7 or 9x9 generally gave better accuracy. In Case 2-2, window size of 5x5 was best.

6) Using double window did not give good accuracy. Considering that CPU-time is long and Maximum error was still high, this method is not effective.

3.3 Image Correlation of Test Areas

Under the following conditions, digital image correlation was applied for three test areas.

Size of window	: 7 x 7
Use median filter	: In case of Method 2-2, DTM of no filtered were also compared with DTM of median filtered.

Table 2 shows the discrepancy of image correlation in test areas. The followings were known from this test.

1) The method of best height accuracy is the method of using the condition of same intersection point. Standard deviation of the method 2-2 is from 11 to 14m. In flat area, the accuracy is about 10m.

2) The area of large error using triplet matching is smaller than that of using stereo matching. However, both method 1 and method 2-1 using right image were wandering near steep slopes.

3) In the area of snow covered, the distributions of snow were changed for each image, but the large error was not exist.

4) The biases depend on the test area and the method. The reason may be the systematic error of orientation or some other factors.

By comparing the distribution of discrepancy and existing maps, the areas of large error were depend on the image correlation methods. However, they were distributed near steep slopes. The correction of window will be necessary to avoid large error.

Table 1-a

Case 1-1 (C,L B/H=0.20)
(no filter)

size of window	Maximum error on PLUS (m)	Maximum error on MINUS (m)	BIAS (m)	RMSE(m)	STDEV(m)	CPU-TIME
5	143	-187	-26.5	35.81	24.10	68
7	137	-165	-26.6	33.04	19.60	69
9	118	-178	-27.4	33.13	18.64	93
11	132	-169	-27.1	33.13	19.07	125
13	62	-187	-27.1	33.60	19.88	162
15	29	-166	-27.4	34.46	20.90	208
19	118	-144	-27.1	36.37	24.26	315
21	94	-170	-27.3	37.37	25.52	380
25	122	-164	-27.6	40.73	29.66	527
29	158	-165	-27.4	43.47	33.75	698
33	161	-198	-26.8	46.09	37.50	878

Table 1-b

Case 1-1 (C,L B/H=0.20)
(Median filter)

size of window	Maximum error on PLUS (m)	Maximum error on MINUS (m)	BIAS (m)	RMSE(m)	STDEV(m)	CPU-TIME
5	41	-133	-27.0	30.86	14.98	86
7	26	- 94	-27.2	30.48	13.72	106
9	25	- 92	-27.5	30.96	14.28	131
11	33	-124	-27.4	31.26	15.12	163
13	58	- 99	-27.6	32.09	16.35	200
15	38	- 96	-27.9	32.99	17.64	248
17	46	-118	-27.5	33.35	18.90	296
19	77	-117	-27.4	34.74	21.30	354
21	100	-142	-27.8	36.08	22.91	422
25	109	-144	-28.2	39.18	27.20	567
29	136	-177	-27.5	41.70	31.29	721
15, 7	54	- 87	-27.6	31.27	14.68	574
15, 9	41	-130	-28.0	31.71	14.78	567

Table 1-c

Case 1-2 (C,R B/H=0.52)
(Median filter)

size of window	Maximum error on PLUS (m)	Maximum error on MINUS (m)	BIAS (m)	RMSE(m)	STDEV(m)	CPU-TIME
5	74	-529	-37.0	73.54	63.56	129
7	49	-104	-23.8	26.91	13.60	170
9	45	- 92	-22.9	27.16	14.61	221
11	55	- 94	-23.7	28.67	16.06	286

Table 1-d

Case 2-1 (Median filter)

size of window	Maximum error on PLUS (m)	Maximum error on MINUS (m)	BIAS (m)	RMSE(m)	STDEV(m)	CPU-TIME
7	35	- 97	-23.9	27.23	12.98	268
9	53	- 77	-23.6	27.27	13.70	349
11	51	- 54	-24.4	28.73	15.18	444
15, 7	262	-234	-24.2	31.12	19.40	1456
15, 9	290	-236	-24.6	32.56	21.35	1518

Table 1-e

Case 2-2 (Median filter)

size of window	Maximum error on PLUS (m)	Maximum error on MINUS (m)	BIAS (m)	RMSE(m)	STDEV(m)	CPU-TIME
5	34	- 83	-23.5	26.54	12.26	124
7	34	- 73	-24.1	27.11	12.31	186
9	30	- 80	-24.7	28.30	13.77	271
11	43	- 83	-25.5	29.55	14.97	371
13	47	- 87	-25.6	30.54	16.71	514
15	51	- 95	-25.7	31.63	18.51	680
17	56	-108	-26.1	33.01	20.19	813
19	65	-120	-25.2	33.73	22.45	1011
21	64	-117	-24.9	34.50	23.92	1232
25	81	-136	-24.3	36.94	27.77	1720
29	98	-140	-23.5	38.73	30.74	2287

Table 2-a

Method 1
(Median filter)
(window of 7x7)

Test area	Case	Maximum error on PLUS (m)	Maximum error on MINUS (m)	BIAS (m)	RMSE(m)	STDEV(m)
1	1-1	192	-189	-23.8	32.93	22.73
	1-2	153	-868	-38.7	101.62	94.00
2	1-1	304	-226	-27.3	30.23	29.03
	1-2	291	-237	-29.0	23.38	21.58
3	1-1	226	-248	-31.0	38.62	22.98
	1-2	128	-237	-28.0	34.50	20.07

Table 2-b

Method 2
(window of 7x7)

Test area	Method	Maximum error on PLUS (m)	Maximum error on MINUS (m)	BIAS (m)	RMSE(m)	STDEV(m)
1	2-1	144	-864	-32.9	83.74	77.08
	2-2 (filter)	47	- 91	-22.3	26.18	13.67
	2-2 (no filter)	195	-291	-21.8	27.38	16.55
2	2-1	155	-181	8.8	16.81	14.35
	2-2 (filter)	119	- 74	6.6	13.25	11.47
	2-2 (no filter)	278	-133	7.2	17.03	15.43
3	2-1	96	-158	-28.3	32.00	15.03
	2-2 (filter)	43	-111	-28.2	30.33	11.06
	2-2 (no filter)	112	-162	-28.2	32.19	15.47

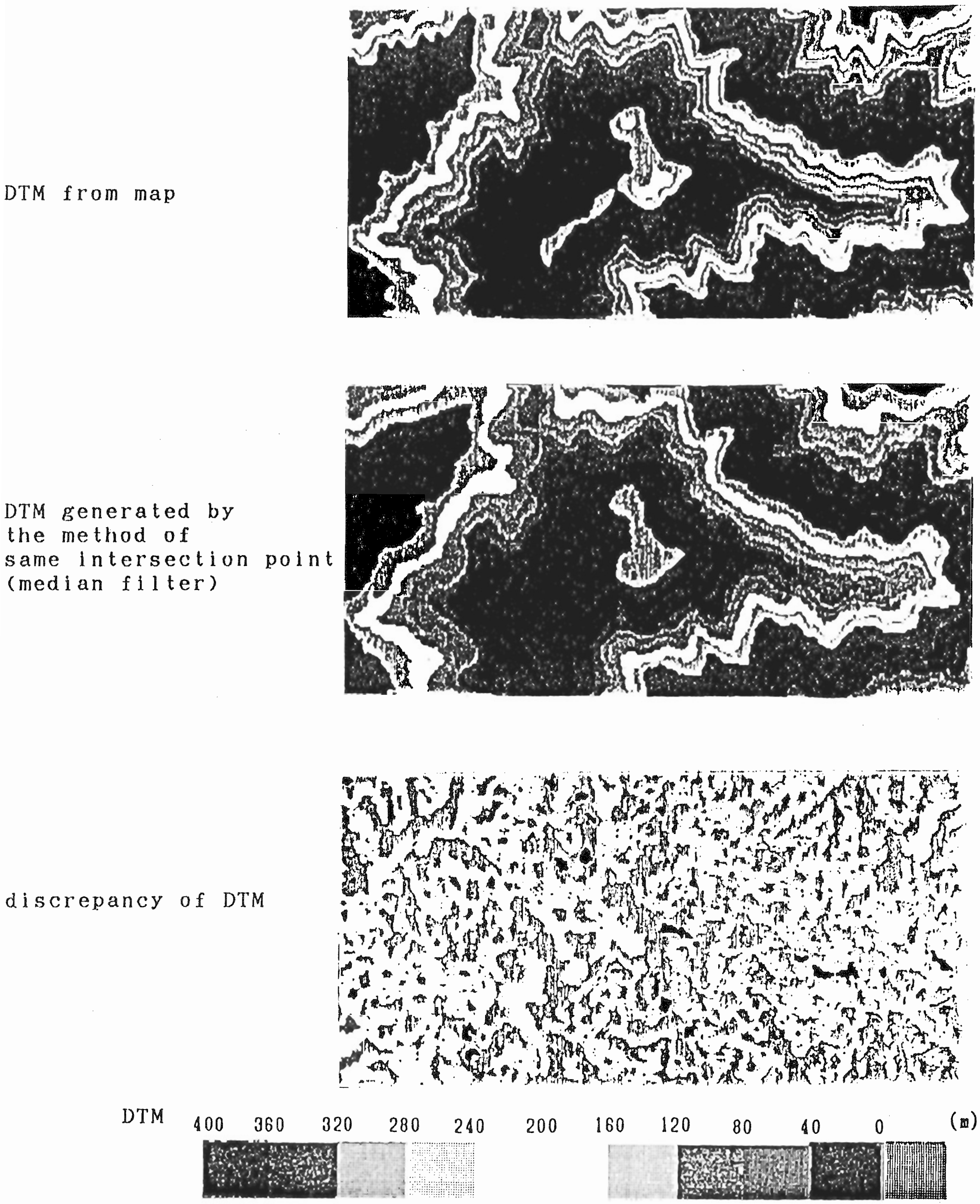

Figure 4 DTM in Test Area 1

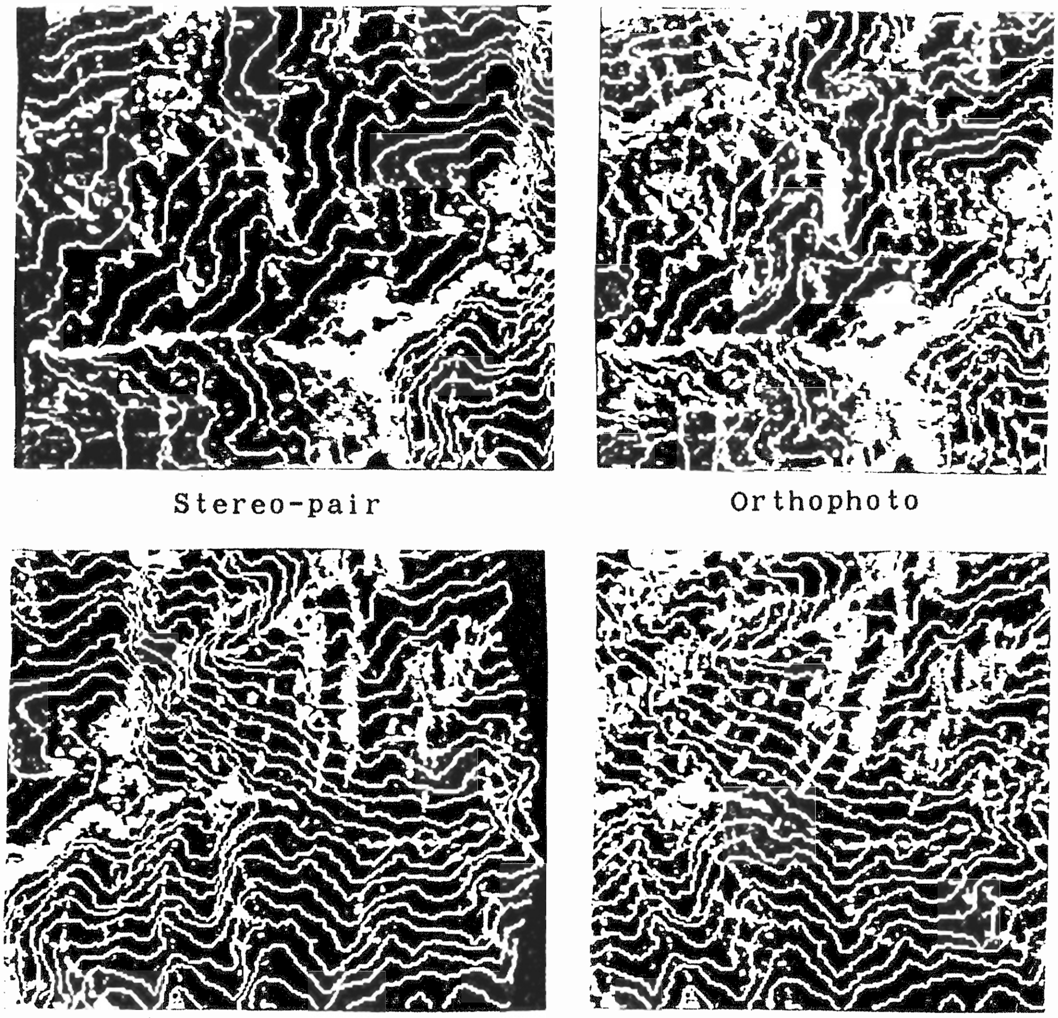

Figure 5 Orthophoto and stereo pair (30 degree, contour interval is 50m) using DTM from method 2-2

4.Conclusion

The image correlation methods which were simply using stereo pair and triplet matching were applied for SPOT image near Mt. Fuji.
Triplet matching using the condition of same intersection point highly improved the accuracy of DTM.

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2) R.Shibasaki S.Murai; "A Simulation on Improvement of the accuracy and the Stability of Stereo Matching using Triplet Linear Array Sensor Data" Journal of the Japan Society of Photogrammetry and Remote Sensing, Vol 26, No.2, 1987, pp4-10